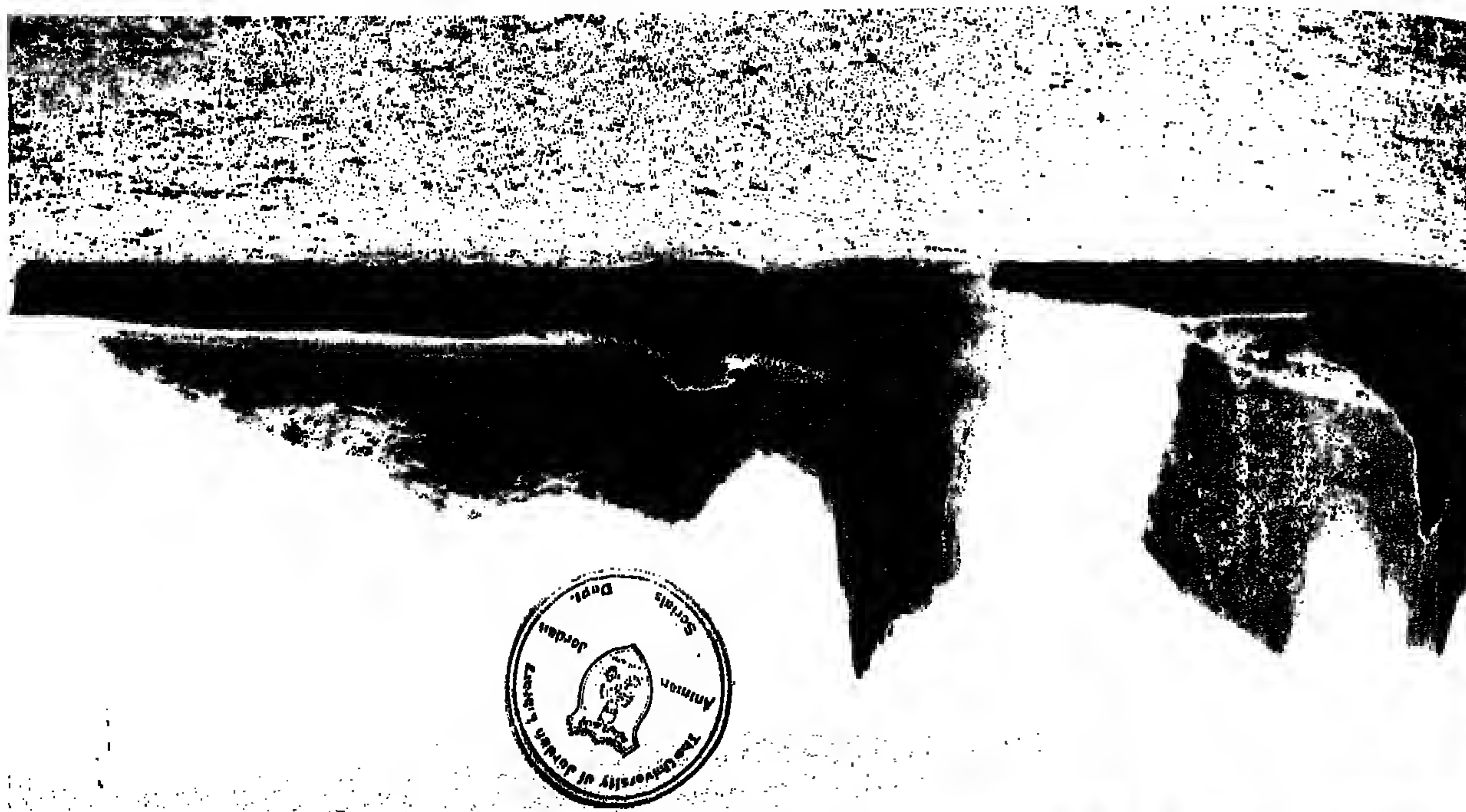

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The Impact of VLBI and GPS on Geodesy

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Two new technologies, Very Long Baseline Interferometry (VLBI) and the Global Positioning System (GPS), will provide the means for achieving the perennial goal of geodesists—a unified, worldwide geodetic control point network tied to an inertial reference system. VLBI will replace optical methods for determining both polar motion and rotation rate, with accuracies an order of magnitude better and with results available a week or less after observations. GPS will permit rapid, economical point positioning with accuracies of a few centimeters over distances of 100 km or more. The potential of these new systems will generate new applications for geodesy and require a reevaluation of the role of geodesists.

Introduction

By today's standards, the establishment of geodetic control networks over the last few centuries has been agonizingly slow. This is so in part because of the relatively meager resources devoted to this purpose; but paucity of funds and personnel are only a part of the explanation for slow progress. At least equally responsible are the stringent requirements for accuracy placed on geodesy and the lack of adequate technology to achieve these accuracies.

Lack of resources and adequate technology have certainly been limiting factors, but perhaps the primary reason geodetic networks are not as complete as we would like them to be is the enormity of the task. A principal goal has been to cover the earth with a network of monomented control points, accurately positioned in a three-dimensional, universal, inertial coordinate system. Considering the obstacles that geodesists have had to face, this goal was considered by many to be virtually impossible. However, technological developments over the last generation have changed the skepticism to a growing confidence that we can eventually reach this goal. Many new techniques are now available. Two of the developments largely responsible for this new confidence are Very Long Baseline Interferometry (VLBI) and the Navigation Satellite Timing and Ranging Global Positioning System (GPS).

Obstacles and Inadequacies of Geodesy

In order to fully appreciate the expected impact of VLBI and GPS on geodesy, one must be at least superficially familiar with the problems that have faced geodesists and the shortcomings of the methods and instruments that were available to solve them. A short review is provided for this purpose.

Pre-Satellite Geodesy

Ever since the ancient Greeks first took an interest in the size and shape of the earth, investigators have been attempting to determine the earth's dimensions and the locations of features on its surface. During most of this time, work has proceeded under the handicap of confinement to the earth's surface. Because direct measurements of bearing and distance could be made only between points which were intervisible, directly connected points could be no further away than the horizon. To measure longer distances and determine the relative positions of widely separated points, chains and networks of intermediate points, each one visible from its immediate neighbors, were established and linked together by measurements.

This procedure worked reasonably well for establishing control point networks across land masses. New points were added and tied to existing points until the network covered the entire area of interest. The inability to see or measure further than the horizon, however, resulted in nonuniform coverage and network voids because large bodies of water and inaccessible land areas could not be bridged by linked control points. For the same reason, continental and island networks could not be tied together by direct measurement to form a continuous network.

In order to overcome this obstacle, geodesists resorted to indirect connections using astronomic observations. Astronomic determinations of latitude and longitude at widely separated points provided some information on their relative positions, but a lack of detailed knowledge of values of gravity severely limited the accuracy that could be obtained.

The introduction of airborne distance measuring devices was a major step in extending the range of measurements. Most such devices, including those that are currently in use, were designed for navigation, not for geodesy. Geodesists adopted systems like SHORAN and HIRAN to measure distances from known to unknown stations. Large trilateration networks were formed to connect chains of islands separated by hundreds of kilometers, and existing continental networks were extended into previously unsurveyed areas. Like astronomic observations, however, accuracies were limited by an inability to fully account and correct for all disturbing influences. In addition, interstation distances were limited by aircraft altitudes.

This inability to bridge oceans with acceptably accurate measurements effectively blocked the establishment of global geodetic networks. Networks covering contiguous territories were established to accuracies ranging from 2 to 10 m, but accuracies of ties across oceans were no better than 100 to 200 m, and there were very few of these. As a result, independent, isolated networks and reference datums were the norm. Prior to the launching of artificial satellites, there were 19 datums which controlled areas of 200,000 km^2 or more, and well over 100 minor or provisional datums.

Satellite Geodesy

With the launching of artificial satellites in 1957, geodesy entered a new era. Satellites provided both a need for improved geodesy and the means for satisfying the need. Accurate orbit predictions required more accurate geodetic coordinates of tracking stations in a common reference system and a more accurate description of the earth's gravity field. Upgraded position coordinates were also needed for evaluation and calibration of satellite tracking instruments [*National Aeronautics and Space Administration*, 1977].

There followed a period of intense activity to promote and exploit the new space technology, and geodesy played the roles of both recipient and contributor. The possibilities for intercontinental observations provided by satellites were so numerous and promising that tracking and observing systems of almost every conceivable type proliferated.

Optical systems observed directions; radar and laser systems measured ranges; Doppler systems measured range rates. In addition to the variety of observing techniques, the procedures for obtaining geodetic information varied. A purely geometric analysis could be carried out by simultaneous observations from two or more stations, yielding the positions of the observing stations relative to each other. A more comprehensive analysis could be performed by determining the satellite's orbit, so that information on the earth's gravitational field and geocentric station positions could be obtained as well.

The profusion of satellites and satellite tracking systems, many of which were designed for specific purposes only indirectly related to geodetic needs, generated enormous amounts of data which enabled geodesists to take giant steps toward their goal of truly global geodesy. The accuracy of connections between the major datums improved steadily from the 100 to 200 m of the pre-satellite era to the 2 to 10 m of today. A global geoid covering the previously unsurveyed oceans and remote continental areas was quickly established and has undergone continuing refinement since. The earth's shape and dimensions and the relationship between mass-centered and best-fitting ellipsoid coordinate systems have become known to an accuracy of almost 1 m.

Current Technologies

Geodesists today use three types of surveying techniques for geodetic control-network point positioning. The first is traditional terrestrial surveying using line-of-sight direction and distance measurements; the second is inertial surveying; and the third is Doppler satellite surveying [*Chrzanowski et al.*, 1983].

Traditional surveying, with theodolites and geodimeters, has virtually reached its limits of accuracy, economy, and efficiency. The methods produce relative positioning accuracies of one part in 10^5 of interstation distances over distances ranging up to 20 to 30 km, which is generally adequate for local needs. As is well known, however, traditional methods are labor intensive and slow, and unfavorable error propagation seriously degrades accuracies over longer distances. Its most serious limitation is the requirement for station intervisibility.

Inertial surveying methods are much faster than the traditional methods and have the added advantage that stations need not be intervisible. Accuracy is in the 20 to 40 cm range over distances of 5 to 100 km. An adverse consideration is the relatively large bulk and cost of the equipment.

Doppler surveying techniques, using the TRANSIT navigation satellites, produce 20 to 50 cm accuracies over distances of 5 to 1000 km. The equipment is relatively compact and can be backpacked. Like inertial surveying, stations need not be intervisible, but unlike inertial methods, observing periods average about 2 days to acquire an adequate number of satellite passes.

Geodesy requires that the earth's orientation and rotation rate with respect to a fixed reference system be periodically observed. Rotation rate, which is needed for determining time, hence longitude, is currently obtained from regular stellar observations made from as many as 50 observatories positioned around the earth. The program is operated by the Bureau International de l'Heure (BIH) in Paris.

There are two serious deficiencies in the current methods. First, the methods use optical telescopes for observing stars. The vagaries of the stars' proper motions and the effects of atmospheric refraction on optical observations limit the obtainable accuracies. Second, the values are not available until well after the observing period; we need to determine earth rotation and polar motion to accuracies commensurate with our point positioning procedures, and these values should be available during, or immediately following, the observing period.

VLBI and GPS: The New Era in Geodesy

Each of the advances in geodetic technology has contributed greatly to the progress of geodesy in some specific area. With the possible exception in gravimetric geodesy, however, no single advance has had an impact great enough to be considered revolutionary. Because of limitations of mobility, accuracy, speed, cost, reliability, or availability, no new system has completely replaced conventional, competing methods. For example, in spite of certain superior performance characteristics of Doppler and inertial surveying systems, a larger proportion of new, horizontal geodetic control points is still being established by terrestrial direction and distance measurement methods. This is true in part because most geodetic surveyors already own theodolites and geodimeters and are reluctant to change, but this is not the main reason.

Revolutionary changes from established, proven methods to radically new methods only come about when the new method is so overwhelmingly superior in enough aspects as to render the old methods obsolete and uneconomic by comparison. None of the satellite-age technologies has reached that stage thus far, but we are on the threshold of just such a revolution with two new technologies: VLBI and GPS. Some of the improvements over current geodetic techniques to be gained by the advent of the VLBI/GPS combination are the following items.

- Reduced need for labor
- Improved accessibility to users
- Higher benefit/cost ratio
- Automated data flow
- Centimeter-level accuracy
- Temporal resolution adequate for all users
- Quick, economical establishment of stations at even remote locations

VLBI

VLBI employs multiple radio astronomy antennas to simultaneously observe signals from extragalactic radio sources such as quasars. The time-tagged signals received at each antenna are cross-correlated to determine common signal arrival times, which together with the speed of light and known directions of the sources can be used to determine the components of vectors connecting the observing stations. If three widely separated antennas simultaneously observe a sufficient number of sources, then the orientation of the earth with respect to the essentially inertial coordinate system of radio sources can be determined for each observational epoch. Repeated determinations at regular, frequent intervals provide a precise record of the dynamic behavior of the earth as a whole, as well as changes in the relative positions of the antennas on the earth's surface.

The accuracies which can be achieved by VLBI are unprecedented. Polar motion, which optical methods could determine to no better than 0.5 to 1.0 m at best, will be determined to 5 to 10 cm in each component. The rotation rate of the earth (UT1-UTC) will be obtained to better than 10^{-4} s. And the components and lengths of vectors between stations separated by as much as a few thousand kilometers will be obtained to 1 to 5 cm. What is perhaps most amazing is that these accuracies will be achieved during observing periods of less than 1 day.

Observations can be made day or night in most weather conditions, thereby assuring a high probability of successful, simultaneous observations from all participating stations. Final results have already been completed within 2 weeks after the observing period, and it is expected that this time can be reduced to 1 week or less when procedures have been further refined.

The potential of VLBI has generated interest and enthusiasm throughout the world. In 1978, a Joint Working Group of the International Astronomical Union (IAU) and the International Union of Geodesy and Geophysics (IUGG) organized project MERIT (Monitor Earth Rotation and Intercompare the Techniques of observation and analysis) to test the concepts and operational feasibility of VLBI and other modern observational techniques. A short observational campaign was conducted from August through October 1980 to test techniques and refine arrangements for international cooperation. The MERIT Main Campaign will span a full cycle of the 14-month Chandlerian component of polar motion, from September 1983 through October 1984.

In the United States, the National Geodetic Survey [NGS] is engaged in project POLARIS (Polar-Motion Analysis by Radio Interferometric Surveying), a project set up to equip and operate three fixed radio observatories dedicated to geodetic applications. The first began operating in Texas in September 1980 and the second in Massachusetts in June 1981. These two have performed one simultaneous 24-hour observing session per week for almost 2 years. A third, in Florida, will begin operating in September 1983.

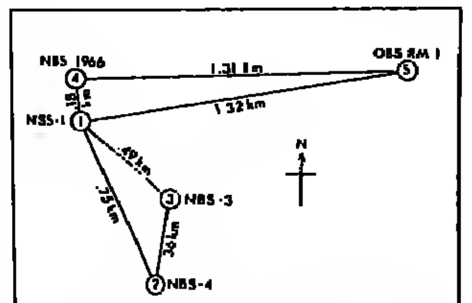

Fig. 1. FGCC test short baseline diagram.

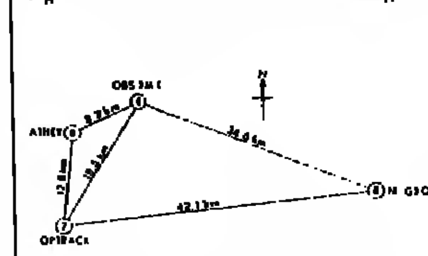

Fig. 2. FGCC test baseline diagram.

GPS

GPS is under development by the U.S. Department of Defense as a worldwide, all-weather navigation and timing system. When fully deployed, GPS will allow suitably equipped users to determine instantaneously (or nearly so) their position and velocity. Furthermore, users with specially equipped receivers and longer observing periods will be able to determine absolute point positions and relative positions with greater accuracy, at lower cost, and in less time than any other method available.

When the GPS system is fully configured in 1989, there will be at least 18 satellites, 3 in each of 6 evenly spaced orbital planes. The satellites will be maintained in near-circular, 55° inclination orbits of 20,200 km radii (12-hour periods). This configuration is designed so that usually four to seven satellites will be visible from any point on the earth at all times. Orbit geometry will be monitored and maintained by the Control Segment of the GPS program through high-precision tracking and orbit determination and orbit-keeping activities. Definitive ephemerides along with ultraprecision timing will be frequently inserted into the GPS satellites for subsequent and continuous transmission to the user community.

To date, seven satellites have been launched and five are still in operation. A minimum of five useful satellites will be maintained until the full constellation is deployed. These five are configured so that three to five are in view, in selected locations, a few hours each day—a configuration considered adequate for purposes of development and system testing.

Just as with the TRANSIT satellite Doppler positioning system, GPS satellites will permit either absolute point positioning of ground stations relative to the known satellite positions, or relative positioning of two or more ground stations which observe common satellites simultaneously. Because of a number of improvements, however, GPS will produce position accuracies as much as an order of magnitude better than is possible with the TRANSIT satellites. GPS satellites are in higher, more stable orbits and can be tracked more accurately than TRANSIT satellites. GPS also uses higher frequency signals and much more accurate clocks. And the 18-satellite array will permit uninterrupted observing of satellites for as long as necessary.

Article (cont. on p. 570)

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Article *(cont. from p. 569)*

Accurate point positioning will require having access to the special signal modulation and the precise satellite ephemerides, information which might be available only to authorized users. Relative positioning, using radio interferometric methods similar to those used in VLBI, however, is independent of the special code. The coded signals are treated as random noise, much like the signals from quasars, to obtain interstation vectors.

Several types of geodetic GPS receivers are in various stages of manufacturing and testing. The first receiver to become commercially available is the MACROMETER Model V-1000 Interferometric Satellite Surveyor, manufactured by Macrometrics, Inc., of Woburn, Mass. The receiver tracks only one of the two transmitted frequencies and is thus limited over longer baselines due to ionospheric effects. The company plans to produce a two-frequency receiver in the future.

An independent test of the MACROMETER V-1000 was conducted over an 8-day period in January 1983 by the Instrument Subcommittee of the U.S. Federal Geodetic Control Committee (FGCC). The tests were conducted on the FGCC test network in the vicinity of Washington, D. C., between stations positioned by first-order terrestrial methods [*Hothem and Fronczek*, 1983]. Three receivers were used to measure two sets of baselines. The first set, shown in Figure 1, consisted of two triangles with sides varying in length from 0.18 to 1.32 km. The second, shown in Figure 2, had side lengths varying from 8.7 to 42.1 km. Results of baseline comparisons are shown in Tables 1 and 2, respectively. In Table 2, all MACROMETER-determined baselines were lengthened by 1:492,000 to compensate for an apparent systematic scale difference between terrestrial and GPS results. Observations on the short-line network were obtained during 2-hour observing periods. The longer-line observations were over 3-hour periods.

The results of this test demonstrate the revolutionary capability of the GPS system. As shown in the tables, all of the shorter baselines agreed with the terrestrial values to better than one part per 50,000. The longer baselines agreed, after scaling, to better than one part per million (ppm). Prior to scaling, the baseline differences ranged from +1.8 to +11.3 cm, and the proportional differences ranged from 1:367,000 to 1:677,000. Both the shorter and longer line results compare favorably with the manufacturer's estimates of ± (5 mm + 5 ppm).

TABLE 1. FGCC Test Short Baseline Comparisons

Observing Dates	Stations From	Stations To	Lengths, km	Length Differences (Terrestrial Minus GPS) cm	Proportional
1/14/83	1	2	0.75	0.0	
1/17/83	4	1	0.18	−0.4	1: 51,000
1/17/83	1	5	1.32	1.1	1:125,000
1/17/83	3	4	1.31	1.7	1: 75,000
1/18/83	1	2	0.75	0.4	1:195,000
1/18/83	2	3	0.36	0.6	1: 62,000
1/18/83	3	1	0.49	0.0	

TABLE 2. FGCC Test Baseline Comparisons

Observing Dates	Stations From	Stations To	Lengths, km	Length Differences,* Terrestrial Minus GPS cm	ppm
1/19/83	7	8	12.8	−0.8	−0.6
1/19/83	7	5	18.5	−0.1	−0.1
1/19/83	5	6	8.7	0.6	0.7
1/20/83	7	8	42.1	2.1	0.5
1/20/83	7	5	18.5	0.0	
1/20/83	5	8	34.6	−1.7	−0.5
1/21/83	7	8	42.1	2.7	0.6
1/21/83	7	5	18.5	−0.4	−0.2
1/21/83	5	8	34.6	1.0	0.3

*MACROMETER baselines scaled by +1:492,000.

Future Impact of VLBI and GPS

After slightly more than 14 years of development and refinement, geodetic VLBI has reached a point where there is now general consensus that VLBI will prove to be a very powerful and cost-effective method of obtaining measurements which are vital to several aspects of geodesy and geophysics. There are a number of technical problems remaining which have not been completely resolved, and improvements will be made in operating and data reduction procedures to shorten the time between observations and dissemination of results, but these are little more than minor annoyances which are common during the shakedown period of any new technology. The major problems have been solved, tests have proven the methods, and observatories are routinely producing results.

When fully operational, a network of as few as 3 VLBI observatories will replace the 50 optical observatories which now monitor the earth's rotation. The International Latitude Service, which monitored polar motion from five optical observatories has ceased operations and is in the process of being supplanted by VLBI. For the first time, a single system, capable of all-weather operations, will monitor both polar motion and rotation rate. Results will be an order of magnitude better than at present and will be available in a week or less instead of 6 months. The positional stability of extragalactic radio sources and the extremely high precision of interferometric measuring techniques are combined in VLBI to provide an inertial reference system which will meet the most stringent accuracy requirements of today and for the foreseeable future.

In addition to providing an absolute external reference framework, VLBI will also provide the ability to monitor continental and worldwide network deformations caused by crustal motions. Portable VLBI antennas in conjunction with fixed base antennas can periodically redetermine the relative positions of widely separated network control points to subdecimeter accuracies. The NGS, in cooperation with other U.S. agencies, is establishing a 50-station National Crustal Motion Network for this purpose. This network will be a level higher than the primary, or first-order, networks of today because of its superior accuracy and the addition of a fourth dimension—time.

Looking beyond the MERIT campaign, the NGS and a consortium of geodetic agencies in the Federal Republic of Germany plan to continue to work together closely. In 1983 the organizations signed a cooperative agreement which will remain in effect as long as it is deemed beneficial to the participants. This agreement established project IRIS (International Radio Interferometric Surveying) which is intended to serve as a foundation for multinational geodetic VLBI programs. Application has been made to the IUGG and the Committee on Space Research to establish IRIS as a subcommission of the International Association of Geodesy's Commission VIII. There is a growing awareness of the power of VLBI, and the geodetic community is moving quickly to apply that power to the solution of problems posed by the modern earth sciences. Several nations have already begun to develop programs and facilities that should lead to a global network of geodetic VLBI observations by the close of this decade.

Simulations and operational tests have provided evidence in support of predictions of the accuracy and efficiency of GPS. As with VLBI, problems remain, but they do not appear to be insurmountable. By the time the full 18-satellite configuration is deployed in the late 1980's, geodetic receivers and operating procedures will have been further refined. Relative accuracies of a few centimeters over baselines up to 100 km, in about an hour of observations, will be routine. The cost of equipment, which is currently in the neighborhood of $250,000 for a pair of dual-frequency interferometric receivers and supporting hardware, should be considerably lower. Equipment will be automatic, operators will need minimal training, field crews will consist of hardly more than one person per receiver, and the production of network control point positions will be increased as much as twenty times per person compared to terrestrial surveying methods.

There is little doubt that GPS will replace terrestrial methods for most main-scheme horizontal control network surveying, but the ability to span distances of 100 km or more on each line will probably mean that new networks in previously unsurveyed areas will initially have far fewer stations, and these will be at points more easily accessible than the hilltops so common in terrestrially established networks.

Network densification will also be accomplished by GPS, but it may be done only as the need arises for specific purposes, rather than as blanket coverage for all future needs. The speed and economy of GPS geodetic positioning, and the cost and susceptibility to disturbance of permanent geodetic markers, may result in the use of temporary markers which can be removed and reused after they have served their purpose.

With a little imagination, many more applications could be listed for a tool as powerful as GPS. And if the prices of the equipment drop drastically, as expected, this will be an incentive for even more applications.

The combination of VLBI and GPS gives us the ability, if we so desire, to finally unify the control point networks of the world into a homogeneous world system. Further, it is no longer necessary to treat the networks as a static system for lack of the ability to detect and keep track of crustal movements. The speed, accuracy, and economy of these technologies, and their ability to span long distances without recourse to intermediate points, will enable us to resurvey worldwide networks of monitoring points at short intervals of time.

The changes to be wrought by the VLBI/GPS system are far more than just replacing one technology with a newer one to perform the same functions. Reaping the full benefits from these powerful new tools will require that we reevaluate and perhaps redefine the functions themselves. In the future, the terms first-, second-, and third-order geodetic networks will no longer apply in the same sense. They are a reflection of the abilities and limitations of classical geodetic surveying technology. The new technologies extend our horizons and give new meanings to such concepts as national, regional, and local control. Table 3 illustrates how these terms could be redefined within the United States by the implementation of the POLARIS and National Crustal Motion Network projects. Similar redefinitions will apply to continental and global networks as well.

No one can today foresee all of the effects which these new technologies will have on geodesy, but we can be reasonably sure of several things. Whether we are ready for them or not, changes will occur in rather rapid succession over the next decade. They will be widespread and irreversible. They will affect not only how we position control points, but also our organizational structures and the education, training, and roles of geodesists in the future. The new capabilities will attract new clients and spawn requirements for services which we cannot envision today. In spite of our natural tendencies to resist change, changes will occur. The geodetic revolution has started.

TABLE 3. Redefinition of Geodetic Functions in the United States

Function	Current Techniques	VLBI/GPS Techniques
Fundamental reference system	50 polar motion observatories scattered worldwide	3 POLARIS observatories within the United States
Unified national geodetic control	First-order geodetic network (about 40,000 stations) 5,000 astronomic stations	Crustal motion network (about 50 stations)
Regional geodetic and local control	Second-order geodetic network (about 80,000 stations)	Combined total of current and VLBI/GPS networks (about 220,000 stations)
Local geodetic control	Third-order geodetic network (about 100,000 stations)	

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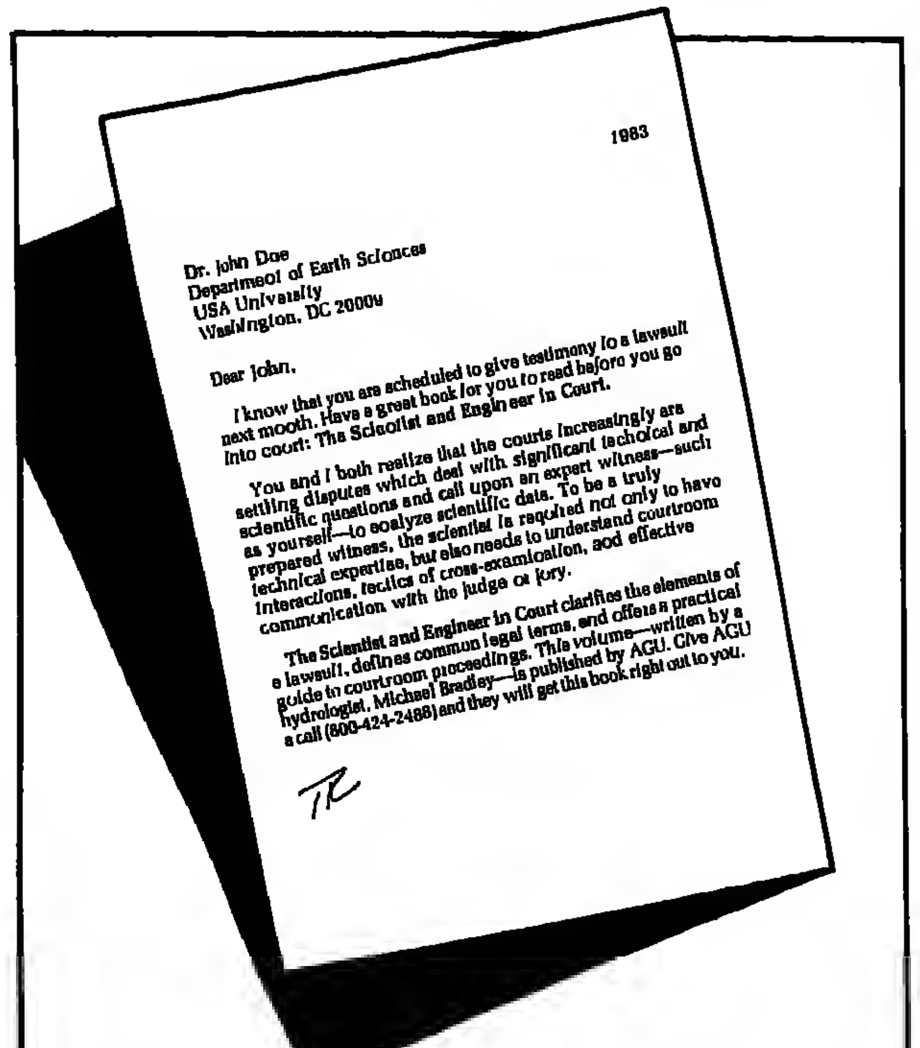

News

Mantle Viscosity

A central factor in models of the earth's interior is the viscosity of the mantle. If regions of the mantle are highly viscous, then solid convection cells may not exist. Conversely, upper and lower mantle viscosity within certain limits could support convection cells ranging from mantle-wide to layered dimensions.

It may not, of course, be possible yet to obtain unique viscosity models for all parts of the mantle because critical boundary values remain undefined or are too uncertain. Nonetheless, the viscosity of the mantle is a basic starting point for many global geophysical models, and the more that can be known about its distribution the more valid the models.

New analyses of LAGEOS (Laser Geodynamics Satellite) data have provided a means of indirect observation of the earth's equipotential surface. W. R. Peltier recently reported analysis of one of the zonal harmonic components, J_2, of the earth's gravitational potential field that was measured over a 5.3-year period by LAGEOS. His conclusion was that the viscosity of the lower mantle is probably quite close to that of the upper mantle, within a factor of 3 or 4. Among the major implications of this conclusion is that mantle-wide convection processes are feasible (*Nature, 304*, 434–436, 1983).

The basic observation was a residual acceleration in the node of the LAGEOS orbit. The interpretation is that this acceleration is, for the most part, due to a secular decrease in J_2. Thus $\dot{J}_2$ is implied to be $-3.5 \pm 0.3 \times 10^{-11}$ yr^{-1}, evidently due to viscous flow in the mantle in response to deglaciation. The relationship between the observation and the implied viscosity of the deep mantle is approximately as follows.

If the earth were an idealized ellipsoid of revolution and thus if the earth's mantle had no finite strength (time-dependent or otherwise), the satellite would travel along an equipotential surface, the geoid. The satellite travel in time would map out a representative, idealized figure of the earth. Deviations from an idealized figure are assumed to be supported by finite strength and rigidity of the mantle.

Two important variables, among others, that affect the results are the variation of strength with depth and with time. It is possible to calculate a strength-depth profile and it is also possible, after sufficient revolutions as in the case of the current LAGEOS data, to recalculate the profile with time. The time profile is sensitive to the accuracy of satellite tracking measurements as well as to changes in the earth's rate of rotation caused by tidal dissipation in the oceans. Peltier used the most accurate tracking data and the time measurements for UT1 (Universal Time) obtained from the Lunar Laser Ranging observations. The nontidal component residual is presumably due to Pleistocene deglaciation effects.

There are many possible routes for these calculations involving models and assumptions about the surface distributions of mass. In the instance of glacial ice caps, the models involve factors of isostatic adjustment and related contributions to the earth's axial moments of inertia. Peltier invoked various geophysical observations to reduce the calculated satellite data. The result is a constraint on the lower mantle viscosity (ν_{LM}) as follows:

$$2.7 \times 10^{22}\ \mathrm{P} \leq \nu_{LM}\ (\mathrm{LAGEOS}) \leq 4.4 \times 10^{22}\ \mathrm{P}$$

This value is close to that of the upper mantle.—*PMB*

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Cover. These two images show the mesoscale sea surface elevation in the South Pacific near Fiji (5°S to 45°S and 158°E to 205°E). These elevations are residuals from about 100 passes of Seasat altimeter data fitted to the NASA Goddard GEM-10B geoid model. The elevations in the top image have been artificially illuminated by a computer simulated sun in the southwest, while those of the bottom image are illuminated from the northwest. The features shown range in elevation from 15 m in the northeast-southwest trending Tonga-Kermadec trench, to a few centimeters for the broad features like the Three-Kings rise (A). This display technique brings out subtle, sea-surface features which cannot be seen in contour maps of these data. In particular note the sea-surface expression of such bottom features as the Louisville ridge (B), the South New Hebrides trench (C), and the Vityaz trench (D). Varying the azimuth of illumination is useful for emphasizing certain features. For example, note the change in appearance of the Manihiki plateau (E, F) between the two images. Several features uncorrelated with known bottom features require further study, particularly the fracture ozone (?) at (B). Parallel linear features trending NE-SW and NW-SE are artifacts of the regridding process and the irregular spacing between parallel passes of data. Regridding results in considerable smoothing of the regions between passes and the lineations are due to differences in sea-surface elevation of a few centimeters between passes separated by 10 km or less. (Photo courtesy of Richard D. Brown, Phoenix Corp., 1700 Old Meadow Rd., McLean, VA 22102.)

Southern Ocean Bathymetry

The southern oceans of the world have not been well surveyed generally, in contrast with oceans of the northern hemisphere. Data from the relatively new Seasat, which is a radar altimeter flown on a satellite platform, has recently provided bathymetric estimates for the southern oceans (*Nature, 304*, 407, 1983). The Seasat data provides a planning data base for future ship surveys to obtain precisely and accurately charted sea-floor topography.

The analysis of a 70-day data set originally collected over the 100-day period from July 5 to October 10, 1978, has revealed a number of distinct bathymetric features that had not been observed before. For example, the new data showed a major rise, or geoid high, that exists east of the Louisville Ridge between latitudes 38° and 41°S, and longitudes 160° and 150°W. The Louisville Ridge itself was found to be a nearly continuous feature composed of short ridge segments. A volcanic rather than a fracture zone origin is suggested by this topography.

Among the other findings are a well defined "hook" along the southeast parts of the Eltanin and Udintsev fracture zone systems, a larger and different shape of the Conrad Rise in the south Indian Ocean, and several smaller rises or plateaus and a large seamount located north northwest of the Marion Dufresne Seamount, also in the south Indian Ocean.

The Seasat altimeter measures the distance between the spacecraft and the ocean surface as deduced from the reflected radar pulses. The radar pulses sample a finite region of the ocean surface, the so-called "footprint," that results from the temporal pulse width of 3.1 ns. The footprint thus defined has a diameter between 2 and 12 km, depending on the state of the ocean surface. The ocean surface character in terms of wave height and wind speed can also be extracted in the measurements.

The analysis includes determination of the radar pulse shape and other properties of the signal. The interaction with the ocean surface, as the pulse is reflected, requires modeling to obtain the travel time to a high degree of accuracy. Among the factors affecting the actual travel times of the pulses are satellite position, atmospheric time delay, geoid height, tides and currents, and variations in atmospheric pressure. The ocean surface height of reference is by definition the sum of all uncorrected, time-invariant contributions to the measurement.

The relationship between the ocean surface and the bottom topography is mostly understood. The greatest effect on the shape of the marine geoid is the bottom topography because of the density contrast between sea water and bottom rock and sediment at close proximity.

As described by T. H. Dixon and M. E. Parke of the Jet Propulsion Laboratory, "The major influence on the ocean surface elevation is the marine geoid. On basin scales (greater than 5000 km) the earth's reference ellipsoid can be as much as 200 m." Variations in ocean current topography are relatively negligible, except for warm-core and cold-core rings such as those that spin off the Gulf Stream and other major western boundary currents.

Dixon and Parke note that the strongest correlation between the geoid and the ocean floor result from features having wavelengths from 30 to 300 km. As they stated, "Where age constraints for topographic features and underlying crust are available, high-quality altimeter data can be used to predict sea-floor topography to better than 500 m along individual altimeter ground tracks."

The Seasat observations were limited in the period of observations and were high-pass filtered to remove long wavelength trends in the altimeter data, due in part to errors in tracking the satellite's position. The geoid anomaly map which resulted from the analysis carries the assumption that no density anomalies lacking topographic expression exist. Further, spatially variable compensation mechanisms could be operative to conceal existing bathymetric anomalies. Thus the greatest value of the study was to pinpoint areas for selection in future ship surveys.—*PMB*

Landsat D′ Primed

Problems with Landsat 4, the United States' current operational land remote-sensing satellite, have prompted the National Oceanic and Atmospheric Administration (NOAA) to move up the launch date of the second spacecraft in the advanced land remote-sensing satellite series, Landsat D′, to early 1984, instead of July 1985 as originally scheduled. Four land remote-sensing satellites were proposed for the original series: Landsat D (known as Landsat 4 now that it is in orbit) is the first, Landsat D′ is the second; two more were to follow. However, with the Reagan Administration's eye on commercializing the land and weather remote sensing satellites (*Eos*, May 17, 1983, p. 377, and March 22, 1983, p. 113), the budgets for the last two Landsat satellites were never approved.

The earlier launch of Landsat D′ will help assess the vital spring crop; this information is necessary to establish U.S. farm production policy for 1984 and to assess the economic impact of the potential crop yield.

Landsat 4, launched July 16, 1982, has suffered serious system failures, including the ability to receive data directly from the thematic mapper instrument. The system is now operating at approximately one-half power and further deterioration in power output is expected. NOAA says complete failure is possible at any time.

Information gleaned from Landsat aids in assessing crop yields, monitoring population growth, appraising pollution, monitoring land use, and performing geological analyses related to petroleum and mineral extraction. Nine other nations purchase Landsat data.—*BTR*

Precollege Science Plan Offered

The federal government should help create a system of 2,000 "exemplary" precollege public schools that would lead the country in initiating sweeping changes in science and math education. This is among the recommendations in a recent National Science Board (NSB) report on precollege education that urged increased exposure of students to science and improved teacher quality. The report is unique among recent education reports in that it offers an itemized price tag for its recommendations. The bottom line: a first-year federal government outlay of $956 million.

"The nation that dramatically and boldly led the world into the age of technology is failing to provide its own children with the intellectual tools needed for the 21st century," states *Educating Americans for the 21st Century*. The report is subtitled, "A plan of action for improving mathematics, science, and technology education for all American elementary and secondary students so that their achievement is the best in the world by 1995." A child now entering first grade and following a normal progression will graduate high school in 1995.

Earlier this year the National Commission on Excellence in Education also denounced the quality of education in U.S. schools. In reaction to that report, which was issued this past spring, the Reagan Administration lent a sympathetic ear to the perils of a weak education but maintained that the federal government should limit its support to education. It is unclear whether the administration will echo those sentiments in response to the National Science Board's report.

The NSB report comes from the 20-member Commission on Precollege Education in Mathematics, Science, and Technology, appointed 17 months ago by the NSB, which is the policymaking arm of the National Science Foundation. The commission recommends increasing the amount of time students spend studying mathematics and science. For example, the group recommends a daily minimum of an hour for math and half an hour for science for students in kindergarten through grade 6. For grades 7 and 8, the commission recommends a full year of math, science, and technology for each.

Minimum requirements for high school graduation should be 3 years of high school mathematics (including 1 year of algebra) and at least 3 years of science and technology (including 1 semester of computer science), in the commission's view. Admission to college should require 4 years of high school science (including chemistry, physics, and one semester of computer science) and 4 years of mathematics (including a second year of algebra and course work covering probability and statistics). To achieve these extended requirements, the commission recommends that the school day or school year be extended.

U.S. schools have a shorter instructional year (180 days) than those of other developed countries such as the United Kingdom (200 days), the Soviet Union (204 days), West Ger-

News *(cont. on p. 572)*

News (cont. from p. 571)

many (210 days), and Japan (220 days). Moreover, the average length of the school day in the United States is 5.5 hours; the other countries have school days averaging between 6 and 8 hours. U.S. high school students also take fewer years of mathematics and science courses than high school students in other countries.

High on the NSB commission's list of recommendations is to improve the quality of teaching by retaining and retraining excellent teachers and by attracting new teachers of the highest quality and the strongest commitment. "A substantial number of our nation's 1.17 million elementary school faculty members lack sufficient knowledge, training, and, in many cases, interest to teach mathematics and science effectively," the report states.

Advances in mathematics and science also necessitate additional training for most of the country's 200,000 secondary mathematics and science teachers. "New measures must be developed and exemplary materials and models disseminated for in-service training of large numbers of teachers," the commission maintains. Among these new measures, the commission recommends that state governments develop teacher training programs, but that the federal government be responsible "to ensure that such training is available."

To ensure high quality among newly hired teachers, the report urges states to adopt rigorous certification standards. In addition, universities and colleges should help by setting tougher admission, curriculum, and graduation standards for future teachers.

The report also says that to obtain quality teachers, state and local school systems "should draw on industry, universities, and the military and other government bodies as well as on the ranks of retired scientists, engineers, and teachers."

The new standards of academic excellence can be fostered by establishing at least 1,000 "exemplary" elementary schools and at least 1,000 "exemplary" secondary schools, the commission says. These exemplary schools "will provide a format for emulation by other schools in the school district or state—a major step toward a more general level of excellence."

The commission suggests that these "landmarks of excellence" would allow communities lacking the resources to completely restructure their mathematics, science, and technology education programs to "provide a substantial improvement for those students who are already motivated and ready to learn." The commission felt that the federal government should encourage and partially finance these exemplary schools.

Unlike other reports on the state of the U.S. education system, the NSB's report includes a breakdown of what the recommendations would cost. The commission estimates that the annual federal expenditure would be $956 million for the first 3 years, $680 million in each of the following 2 years, and $331 million for each year thereafter. (For comparison, President Reagan's requested program level for the National Oceanic and Atmospheric Administration's entire fiscal 1984 budget is $843.2 million.)

The largest expense on the itemized list of recommendations is for the exemplary school program. The commission estimates that the program would cost $1.275 billion and that the federal government should contribute a total of $829 million, to be divided into three annual outlays of $276 million. To develop the financial approaches required and to decide how the costs of public education should be shared, the NSB commission says the President should establish a Council on Educational Financing. The council should be appointed immediately, the commission adds, and should issue its conclusions before August 31, 1984.

Also outlined in the commission's report are recommendations to provide a national system for measuring student achievement and to utilize "all available resources, including the new information technologies and informal education."

The National Science Board Commission on Precollege Education in Mathematics, Science, and Technology was cochaired by William T. Coleman, Jr., (U.S. Secretary of Transportation in the Ford Administration) and Cecily Cannan Selby (former dean of academic affairs and chair of the board of advisors for the North Carolina School of Science and Mathematics). Copies of the report are available from the commission, 1800 G Street N.W., Washington, DC 20550.—*BTR*

Newell Library Dedicated

On September 27 the library at the Goddard Space Flight Center in Greenbelt, Md., was renamed the Homer E. Newell Library in memory of the man who was once the National Aeronautics and Space Administration's (NASA) deputy director for space flight programs, director of the Office of Space Sciences, and associate administrator. Newell, who was 68 years old when he died on July 18, 1983, was president of AGU from 1970 to 1972.

A photograph of Newell and a plaque will be permanently displayed in the library. The plaque, which will be framed in walnut, reads, "The Homer E. Newell Library, dedicated September 27, 1983, to honor his leadership and contributions to America's space science program." NASA Administrator James M. Beggs and Mrs. Homer E. Newell were scheduled to participate in the dedication ceremonies.

The library, established in 1961, has 115,000 books and bound journals and serves Goddard, other NASA centers, and the technical community.

In addition to the positions he held at NASA, Newell also headed the Naval Research Laboratory's program on rocket research in the upper atmosphere.—*BTR*

Geophysicists

The National Science Foundation (NSF) announced the following staff changes in the Division of Atmospheric Sciences: *William H. Beasley* to associate program director of the meteorology program; *Andrew B. Christensen* to program director of the aeronomy program; *Thomas Crowley* to program director of the climate dynamics program; and *Hassan Virji* to associate program director of the climate dynamics program.

In NSF's Division of Ocean Sciences *Edward D. Houde* has been appointed program director of the biological oceanography program.

Books

Principles of Forest Hydrology

John D. Hewlett, University of Georgia Press, Athens, 183 pp., 1982, $6.

Reviewed by Edwin T. Engman

Principles of Forest Hydrology has been written to accompany class lectures for students pursuing training in forestry, wildland resources, environmental sciences, and geography. The book introduces basic principles and concepts of hydrology and it does this quite well.

Principles of Forest Hydrology is a revision of an earlier book, *An Outline of Forest Hydrology*, coauthored with Wade L. Nutter. The new version is quite similar to the original with some important additions in the areas of precipitation, subsurface water, and evapotranspiration. Metric units are used in the examples and problems, and the soil water potential terminology has been updated.

The text is organized in a time-proven and logical fashion. An introductory chapter gives the student a good perspective plus an introduction to some necessary definitions. The next seven chapters march the student through the hydrologic cycle starting with water and energy cycles and then introducing basin morphology. A chapter on atmospheric moisture and precipitation is followed by chapters on soil moisture and groundwater, evaporation and evapotranspiration, surface water and the runoff process, and erosion and sedimentation. The last two chapters, "Forests and Floods" and "Forests and Water Quality," discuss the role of forested lands.

To some degree the book reflects the regional experiences of the author. The inclusion of the R index and discussion of partial-area hydrology are important and useful concepts in humid areas; however, the text would be better balanced if it included a discussion of other empirical runoff equations and the runoff processes found in other parts of the world.

The book is easy to read and most of the concepts have been explained very clearly. However, I would like to have seen a more extensive and up-to-date list of "Further Readings" to accompany each chapter. I feel that a good list of reference material is especially important for an introductory text.

I also feel that there are several aspects of modern hydrology that the author did not cover at all or should have covered in more detail. One of these is infiltration. The author explains that in runoff generation, infiltration is generally not the controlling factor that it may be in nonforested soils. This is probably quite true for the humid east but may not be true for all forested and wildland areas. In addition, many resource management applications involve areas of mixed land use. Some introduction to infiltration theory, and some specific references, would make this text more widely useful. The treatment of flood routing also needs to be expanded and updated. The simple storage method is useful for explaining the concept but the process is far more complex than this, and there are a number of computer-aided tools for use in flood routing analysis that are much more up to date. An introduction to watershed models would also add to the book. This type of model (e.g., the Stanford Model) is used by practicing hydrologists for many applications, and the beginning student should be made aware of this tool.

Principles of Forest Hydrology is a good basic text for beginning students in forestry and wildland resources. Its strength lies in the clarity with which it explains the principles of hydrology as a science. Its major limitations are that it does not venture far into quantitative hydrology and the references are limited and not particularly current.

Edwin T. Engman is with the U.S. Department of Agriculture, Agricultural Research Service, Hydrology Laboratory, Beltsville, MD 20705.

New Publications

Items listed in New Publications can be ordered directly from the publisher; they are not available through AGU.

Acid Deposition, Proceedings of a Commission of the European Communities Workshop, S. Beilke and A. J. Elshout (Eds.), D. Reidel, Boston, x + 235 pp., 1983, $32.50.

Advanced Soil Mechanics, B. M. Das, McGraw-Hill, New York, xiii + 511 pp., 1983, $34.95.

Agricultural Management and Water Quality, F. W. Schaller and G. W. Bailey (Eds.), Iowa State Univ. Press, Ames, xviii + 472 pp., 1983, $39.95.

Agricultural Soil Mechanics, A. J. Koolen and H. Kuipers, Springer-Verlag, New York, xi + 241 pp., 1983, $37.

Ancient Sedimentary Environments and the Habitats of Living Organisms: Introduction to Palaeoecology, Springer-Verlag, New York, xxii + 219 pp., 1983.

Buying a Better Environment: Cost-Effective Regulation Through Permit Trading, E. F. Joeres and M. H. David (Eds.), Univ. of Wisconsin Press, Madison, x + 276 pp., 1983, $7.50.

Coated Grains, T. M. Peryt (Ed.), Springer-Verlag, New York, xi + 655 pp., 1983, $58.

Conservation of Water and Related Land Resources, P. E. Black, Praeger, New York, xx + 209 pp., 1982.

Crystal Symmetry: Theory of Colour Crystallography, M. A. Jaswon and M. A. Rose, John Wiley, New York, 190 pp., 1983, $44.95.

Drinking Water Supplies: Protection Through Watershed Management, R. J. Burby, E. J. Kaiser, T. L. Miller, and D. H. Moreau, Ann Arbor Science, Ann Arbor, Mich., 1983, $29.95.

Dynamique des Climats et de L'Écoulement Fluvial, R. Frécaut and P. Pagney (Eds.), Masson, New York, 239 pp., 1983.

Earthquake Forecasting and Warning, T. Rikitake, D. Reidel, Boston, xxii + 397 pp., 1982, $120.

Electronic Surveying in Practice, S. H. Laurila, John Wiley, New York, xiii + 388 pp., 1983, $37.50.

The Exploration of Outer Space With Cameras: A History of the NASA Unmanned Spacecraft Missions, M. M. Mirabito, McFarland, Jefferson, N. C., vi + 170 pp., 1983, $19.95.

Frontiers in Hydraulic Engineering, Hung Tao Shen (Ed.), Am. Soc. Civ. Eng., New York, xv + 617 pp., 1983, $47.75.

Fundamental Concepts in the Numerical Solution of Differential Equations, J. F. Botha and G. F. Pinder, John Wiley, New York, xii + 202 pp., 1983, $24.95.

On the Geodetic Applications of Simultaneous Range-Differencing to Lageos, E. C. Pavlis, *Rep. 338*, Department of Geodetic Science and Surveying, Ohio State Univ. Research Foundation, Columbus, xv + 213 pp., 1982.

Geology, Geological History, and Origin of Qinghai-Xizang Plateau, vol. 1, *Geological and Ecological Studies of Qinghai-Xizang Plateau*, xxv + 974 pp., Gordon and Breach, New York, 1981.

The Great Tolbachik Fissure Eruption: Geological and Geophysical Data 1975–1976, S. A. Fedotov and Ye. K. Markhinin (Eds.), Cambridge Univ. Press, New York, vii + 341 pp., 1983, $69.95.

Ground Water Monitoring Technology: Procedures, Equipment and Application, R. D. Morrison, Timco Mfg., Prairie du Sac, Wis., xv + 111 pp., 1983, $33.

Groundwater Contamination in the United States, V. I. Pye, R. Patrick, J. Quarles, Univ. of Penn. Press, Philadelphia, 307 pp., 1983, $14.95.

Holomorphic Functions of One Variable, S. Colombo, Gordon and Breach, New York, o + 274 pp., 1983, $39.50.

Hydrodynamics of the Equatorial Ocean, Proceedings of the 14th International Liege Colloquium on Ocean Hydrodynamics, J. C. J. Nihoul (Ed.), Elsevier, New York, x + 368 pp., 1983, $63.75.

The Interior of the Earth: Its Structure, Constitution, and Evolution, 2nd ed., M. H. P. Bott, Elsevier, New York, ix + 403 pp., 1982, $35.

Intracontinental Fold Belts: Case Studies in the Variscan Belt of Europe and the Damara Belt in Namibia, H. Martin and F. W. Eder (Eds.), Springer-Verlag, New York, xiv + 945 pp., 1983, $52.

Introduction to Geomagnetism, W. D. Parkinson, Elsevier, New York, viii + 433 pp., 1983, $49.50.

Mathematical Modeling of Water Quality: Streams, Lakes, and Reservoirs, G. T. Orlob (Ed.), John Wiley, New York, xx + 518 pp., 1983, $105.

Methods and Instrumentation for the Investigation of Groundwater Systems, Committee for Hydrological Research TNO, The Hague, The Netherlands, xiii + 690 pp., 1983, $30.

Methods in Rock Magnetism and Palaeomagnetism: Techniques and Instrumentation, D. W. Collinson, Chapman and Hall, New York, xiv + 503 pp., 1983, $70.95.

Minerals, Rocks, and Fossils, John Wiley Self-Teaching Guides, R. V. Dietrich and R. Wicander, John Wiley, New York, 212 pp., 1983, $9.95.

Ocean Science, K. Stowe, 2d ed., John Wiley, New York, xiii + 673 pp., 1983, $27.95.

Ophiolitic and Related Melanges, vol. 66, *Benchmark Papers in Geology*, G. J. H. McCall (Ed.), Hutchinson Ross, Stroudsburg, Pa., xiii + 446 pp., 1983.

Pioneer Venus, R. O. Fimmel, L. Colin, and E. Burgess, *NASA SP-461*, U.S. Government Printing Office, Washington, D. C., xi + 253 pp., 1983.

Principles of Underwater Sound, R. J. Urick, McGraw-Hill, New York, xiii + 423 pp., 1983, $39.95.

Principles of Water Resources Planning, A. S. Goodman, Prentice-Hall, Englewood Cliffs, N. J., xii + 563 pp., 1984, $34.95.

Proceedings of the 17th Assembly of the European Seismological Commission, E. Bisztricsány and Gy. Szeidovitz (Eds.), Elsevier, New York, xviii + 689 pp., 1983.

Public Involvement and Social Impact Assessment, G. A. Daneke, M. W. Garcia, and J. D. Priscoli (Eds.), Westview Press, Boulder, Colo., xli + 303 pp., 1983, $25.

The Radon Transform and Some of Its Applications, S. R. Deans, John Wiley, New York, xi + 289 pp., 1983, $34.95.

Remote Sensing Applications in Marine Science and Technology, Proceedings of NATO Advanced Study Institute, Scotland, 1982, A. P. Cracknell (Ed.), D. Reidel, Boston, xii + 468 pp., $78.

Satellite Microwave Remote Sensing, T. D. Allan (Ed.), John Wiley, New York, 526 pp., 1983, $110.

Seismicity and Seismic Risk in the Offshore North Sea Area, A. R. Ritsema, A. Gürpinar (Eds.), D. Reidel, Boston, xxiv + 419 pp., 1983, $135.

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The postdoctoral position is available beginning January 1984 to do research in the field of fission track analysis applied to studies of sedimentary basins. Applicants must be knowledgeable and experienced in fission track analysis.

Our present department is part of a modern, technologically-oriented university, and consists of seven members whose collective expertise encompasses structural geology, geophysics, geochemistry, petrology, glacial and surficial geology, and ecological modeling. The RPI environment provides ample opportunities for field and laboratory experimental research in geology, as well as for interdisciplinary studies in chemistry, physics, biology, mathematics, materials science, engineering and computer science.

A resume and the names of three persons who would be willing to provide letters of reference should be sent to Donald S. Miller, Chairman, Department of Geology, Rensselaer Polytechnic Institute, Troy, NY 12181.

Rensselaer is an Equal Opportunity/Affirmative Action Employer.

Laboratory Analyst and Manager/South Dakota School of Mines and Technology. Position as acting Assistant Director of Engineering and Mining Experiment Station at state-supported school of engineering and science located adjacent to the Black Hills. Experience required in standard chemical analysis, XRF, XRD, AA (ICP), ES, and energy dispersive analysis. Individual work and supervision of research, student lab work. Position includes engineering materials. Opportunity for individual research, work with graduate students, and instruction in short courses. M.S. degree minimum. Closing date: October 31, 1983.

An Equal Opportunity Employer.

Resume and three references to Jack A. Redden, Director, Experiment Station, South Dakota School of Mines and Technology, Rapid City, SD 57701-3995.

University of Cambridge, Bullard Labs, Seismologist. Postdoctoral research position available in the Marine Geophysics Group. We have an active program involving two-ship multichannel seismic experiments on the UK continental margin, construction of digital OBS, seismic refraction experiments on the continental shelf, the deep oceans, passive and active margins and aseismic ridges, and the development and application of new interpretation methods, with opportunities to initiate new projects. Initially funded for 2 1/4 years.

Send resume and names of two referees or request for further details to Dr. R.S. White, Bullard Laboratories, Madingley Road, Cambridge, U.K.

An equal opportunity employer.

The University of Missouri-Columbia/Faculty Positions. The University of Missouri-Columbia Department of Geology plans immediate expansion through the addition of three tenure-track faculty positions. Appointments are anticipated at the assistant professor level, although higher ranks may be possible, beginning in August of 1984. Candidates will be expected to have completed requirements for the Ph.D. degree by that time. Faculty members are required to provide quality instruction at both undergraduate and graduate level, and conduct research leading to scholarly publications. Successful candidates will be chosen from the following specialties:

Exploration Geophysics
Solid Earth Geophysics
Hydrogeology
Analytical Structural Geology
Clastic Sedimentology

Applications should send resume, transcripts, and names and addresses of three references to:

Tom Freeman, Chairman
Department of Geology
University of Missouri
Columbia, MO 65211

Department of Geosciences/University of Houston. The Department of Geosciences is interested in having applications for tenure track positions in the following areas: (1) Geophysics—seismology, exploration, data processing (2) Petrology—sandstones and metamorphic (3) Geochemistry—diagenesis

Salary and rank commensurate with experience. If interested, please send:

(1) A curriculum vitae
(2) A brief statement of teaching and research interests
(3) Three letters of recommendation to:

Dr. John C. Butler
Department of Geosciences
University of Houston
Houston, Texas 77004

Affirmative-action/equal-opportunity employer.

Chairman, Department of Geological Sciences/Wright State University. The Department of Geological Sciences invites applications for the position of chairman to be appointed September 1984. We seek a dynamic individual with administrative talent and an appreciation for research and practice-related educational activities. Rank is in the full professor level and no restrictions have been placed on areas of specialization. The department is active with 12 faculty and an emphasis on professional practice, yet maintaining a firm commitment in basic research.

Send a letter of application, curriculum vitae and names of three references to:

Chairman, Search Committee
Department of Geological Sciences
Wright State University
Dayton, OH 45435

Wright State University is an affirmative action/equal opportunity employer. Closing date for the position is October 31, 1983.

Professor of Marine Geophysics Tectonics-Stanford University. The Department of Geophysics, Stanford University, is seeking candidates for a tenure track position in the broad area of marine geophysics and tectonics. We seek a creative scientist with experience in gathering, interpreting, and synthesizing marine geophysical data and whose research interests cover depositional, igneous, and tectonic processes on oceanic plates and continental margins. Inquiries are invited from marine geophysicists with demonstrated scientific record in one of the above aspects of marine geophysics or tectonics, who have demonstrated an ability to develop new ideas and research directions, and to guide and teach graduate and undergraduate students. In considering this appointment we are interested in maximizing interactions with ongoing research groups in marine geology, plate tectonics, paleomagnetism, seismology and regional geology at Stanford. Our new faculty member will be expected to develop a strong research program involving both government and industrial participation.

Salary and rank will be commensurate with experience and background. Please submit a resume, a brief description of teaching and research interests, and references to:

Dr. Amos Nur
Department of Geophysics
321 Mitchell Building
Stanford University
Stanford, CA 94305

Stanford University is an equal opportunity employer, and encourages the application of qualified women and minorities.

University of Florida. The Department of Geology invites applications for a tenure-track position beginning with the fall term, 1984. The position will be filled at the assistant or associate professor level. A Ph.D. is required and salary will be commensurate with qualifications. Although any research specialty will be considered, preference will be given to those with interest in these general areas: geochronology-isotope geology or low-temperature geochemistry-chemical sedimentology. Send curriculum vitae and 3 letters of reference by January 15, 1984 to: Dr. N. D. Opdyke, Department of Geology, 1112 GPA, University of Florida, Gainesville, Florida 32611.

The University of Florida is an equal opportunity/affirmative action employer.

AGU

Section Candidates

Eos is carrying biographies and photographs of all candidates for President-elect, General Secretary, and Foreign Secretary of the Union and for President-elect and Secretary of each Section. In addition, statements by the candidates for Union offices and for Section President-elect will appear. The material for the Atmospheric Sciences Section appears below. The material for the Geodesy, the Geomagnetism and Paleomagnetism, and the Planetology sections appeared in the August 30 issue. The slate of candidates for all offices was carried in the June 21 issue.

Atmospheric Sciences: President-elect

Ralph Cicerone A member of AGU since 1971; 39 years old; Senior Scientist and Director of the Atmospheric Chemistry and Aeronomy Division of the National Center for Atmospheric Research. Major interests are atmospheric chemistry and biogeochemistry. Received his S.B. degree from MIT (1965), his M.S. (1967) and Ph.D. (1970) from the University of Illinois. Served on the staffs of the University of Michigan (1970–78) and the Scripps Institution of Oceanography (1978–80) before joining NCAR. An Editor (1980–83) of the *Journal of Geophysical Research*: (Oceans and Atmospheres); he served as an Associate Editor for that journal 1977–79. He is a Fellow of AGU, the American Association for the Advancement of Science and the American Meteorological Society (AMS) and a member of the American Chemical Society.

Presently Vice Chairman, Panel on Atmospheric Chemistry, Board of Atmospheric Sciences and Climate, National Academy of Sciences (NAS); member of the AMS Committee on Air Chemistry and Radioactivity and the AMS Committee on Fellows; and Chairman, 1983 Gordon Research Conference on Environmental Sciences: Air. Has published over 40 papers including 28 in five different AGU journals (JGR Green, JGR Blue, GRL, *Radio Science*, and *Reviews of Geophysics and Space Physics*). Has also presented over 50 papers at conferences, 30 at AGU conferences.

In 1979 was awarded AGU's Macelwane Award "for significant contributions to the geophysical sciences by a young scientist of outstanding ability." In 1981 and 1982 served on the AGU Macelwane Award subcommittee and from 1978–83 was a member of the AMS Committee on the Upper Atmosphere. Previously, he served on the Scientific Advisory Committee for the Federal Aviation Administration's High Altitude Pollution Program (1978–82), the NAS Committee on the Atmospheric Sciences and several other panels and summer-study groups.

Statement

"AGU's Atmospheric Sciences (A) Section is the newest section of AGU. It was created in 1982 to continue the activities of the Meteorology Section and to place more emphasis on the leading role of AGU in atmospheric chemistry, atmospheric electricity, and certain portions of climate and solar-terrestrial effects. It is an honor for me to be nominated in this first A-Section election to succeed our president, Dr. W. N. Hess.

"To assure that AGU avails itself of opportunities and discharges its obligations, AGU Section Officers and Council Members must accept major responsibilities. These include: maintaining and improving the quality of our journals, holding high-quality scientific conferences, representing specific scientific areas on the Council and staying alert to new opportunities. Examples of issues that concern me now are page-charge costs in AGU journals and the continuing growth of our national meetings. On the former question, as an outgoing editor, I have seen a growing number of authors send their papers to non-AGU journals because of page charges in the last 4 years. AGU must place a higher priority on low page charges to serve its members and geophysics. As to the latter question, it has been said that our San Francisco meeting is choking on its success. Options other than the 8-day format need to be reconsidered, including rejection of inadequate abstracts and more AGU topical meetings. I intend to poll A-Section members on this issue.

"I would welcome the opportunity to work with the Atmospheric Sciences Section members, the AGU professional staff, and other AGU officers toward the goals outlined above and new goals as they materialize."

Julia London A member of AGU since 1960; age 66; professor, University of Colorado, since 1961. Major interests: atmospheric physics. B.A., mathematics, Brooklyn College, 1941; M.S., Ph.D., meteorology, 1948, 1951; New York University Res. Assoc., Asst. Professor, Assoc. Professor, New York University 1951–61. Lecture, Columbia, 1954; Visiting Professor, Pennsylvania State University, 1955; Department of Astro-Geophysics, University of Colorado, since 1961; Chairman, 1966–69. Visiting Professor, ETH, Zurich, 1967, 1974–76. Fellow: AAAS, AMS, R. Meteorology Society. Invited lecturer: AMS, Chinese Academy of Science, AAAS (Chautauqua), McGill Summer School.

Member, International Ozone Commission (IAMAP); President, Secretary, International Radiation Committee (IAMAP). Chair, section on Atmospheric and Hydrology Sciences, AAAS (member of Council AAAS). Member, U.S. Wx Bureau Committee on Education & Tr.; AMS board on University Education; AMS Committee on Upper Atmos.; Member AMS Committee on Fellows (Chair); Chair, Panel on Ozone CAS NAS/NRG; Member, Panel on Strat. Chemistry, Committee, Impacts of Strat. Change NAS/NRG; Member, Panel on Earth Science, Committee on Human Resources, NAS/NRC. Member, Board of Trustees, Executive Committee, Nominating Committee (Chair) UCAR; IUGG rep to COSPAR Executive Coun., U.S. rep. to IAMAP; Member WMO/IGSU Working Groups, Cloud and Radiation; Aerosols and Climate. 75 publications (7 AGU journals); contributor to Harpers Encycl.

Editorial: Associate Editor, JGR; Board of Editors, Contributor to Atm. Phys., *Il Nuovo Cimento, Weatherwise*; Editor Advisory Board, Atm. Sci. Libr., Reidel Publ.

Statement

"The Atmospheric Sciences section has the responsibility of providing, within the framework of the American Geophysical Union, a broad forum for its members covering current, forefront problems of physics and chemistry applied to the earth's atmosphere from the surface to about 100 km. I believe that the section should continue to be concerned through its meetings and publications with traditional areas of atmospheric sciences such as weather systems, atmospheric electricity, theories of climate and climatic change, atmospheric energetics, tropospheric and stratospheric chemistry, etc."

"However, because the atmosphere has contiguous boundaries below and above, it is essential that the program of the section interface with other subdisciplines (e.g., solid earth geophysics, cryosphere and oceans, including air/sea boundary problems; and high atmosphere physics, solar physics, including atmospheric responses to solar variability, etc.). It has been our experience that such interactions result in a cross fertilization of benefit to each of the participating disciplines.

"The executive of the Atmospheric Sciences section represents the section in the councils of the AGU and gives guidance to the Council on matters involving the atmospheric sciences community. Thus I would plan to work closely and cooperatively with representatives of the other discipline areas in advancing the interchange of ideas in the geophysical sciences. In this the leadership of the Atmospheric Sciences section not only arranges for scientific sessions at national AGU meetings that reflect the varied interests of the section membership, but can also plan for cross discipline symposia that would attract a broad representation of AGU scientists.

"The growth of the AGU and its different sections depends to a large extent on how well it can attract, stimulate, and involve young graduate and postdoctoral-level students in AGU activities. For many reasons, it has become exceedingly difficult for these younger professional and preprofessional colleagues to participate in AGU activities. I strongly support efforts to strengthen the development of a special fund for travel grants to young scientists to attend AGU national meetings. These grants would be based on recommendations from an AGU member and not be contingent on a formal paper presentation."

Atmospheric Sciences: Secretary

Rex J. Fleming A member of AGU since 1982; 43 years old; Director of the Office of Climate and Atmospheric Research of NOAA. Major interests are climatology and international programs, especially GARP and FGGE. Graduated from Creighton University (B.S. Mathematics) 1963; University of Michigan (M.S. Meteorology) 1968; University of Michigan (Ph.D. Meteorology) 1970.

Systems Analyst, U.S. Air Force, 1963–72; Director ASC Applications/Marketing, Texas Instruments 1972–75; Director U.S. First GARP Global Experiment Project Office 1975–81; Director, Special Research Programs Office; present position, 1983– . International: U.S. representative to WMO FGGE Panel. Led first U.S. Ocean Climate Delegation to the People's Republic of China. NOAA representative to National Academy of Sciences U.S. Garp Committee 1978– , and Climate Research Committee 1980– . American Meteorological Society: Served as Chairman of Committee on Probability and Statistics, 1975–77. Member of AAAS, AGU, American Society of Photogrammetry, and the Oceanic Society.

Published several scientific papers in several professional journals. Awards: Air Force Commendation Medal (1967) for outstanding achievement in numeric analysis; The Department of Commerce Gold Medal Award (1980) for outstanding achievement in directing U.S. role in the Global Weather Experiment. Fellow AAAS.

Dalraju B. Rao A member of AGU since 1979; 46 years old. Since 1980, Head of Oceans and Ice Branch, Goddard Laboratory for Atmospheric Sciences, NASA, and also Adjunct Professor, Department of Meteorology, University of Maryland. Theoretical studies on the free oscillations, free and forced waves, stability of flows, in lakes, oceans, and atmosphere. M.Sc. in Meteorology and Oceanography from India in 1959; M.S. (1962) and Ph.D. (1965) in Geophysical Sciences from University of Chicago. Postdoctoral Fellow at NCAR during 1965–67. Then Assistant Professor of Atmospheric Sciences at Colorado State University during 1968–71; subsequently Associate and Full Professor of Geophysical Fluid Dynamics at University of Wisconsin–Milwaukee during 1971–75. Following this, Head of Physical Limnology and Meteorology Group, Great Lakes Environmental Research Laboratory, NOAA, during 1975–80. Member of AMS, Sigma Xi, and charter member of International Water Resources Association. Vice-President, Denver Chapter of AMS (1969–70). Member of AMS Committee on Atmospheric and Oceanic Waves and Stability. 33 publications in journals (4 in AGU journals) and over 30 unrefereed reports. Fellow of AMS; biographical listing in Who's Who in America, among others.

Membership Applications Received

Applications for membership have been received from the following individuals. The letter after the name denotes the proposed primary section affiliation.

Paolo Boccotti (O), Elizabeth A. Creamer (T), Thomas E. Ewing (V), Russell S. Harmon (V), Richard G. Hart (SS), C. J. Hawkesworth (V), A. Dana Johnston (V), Wayne A. Kinney, Larry E. Kunz (G), Tzeu-Lie Lin (S), Ronald K. A. M. Mallant (A), Hermann J. Maurtisch (GP), Venkat R. Mukku (A), James B. Murdoch (V), Jorg F. W. Negendank, Thomas C. Pierson (H), Michael J. Prather (A), Leah Street (V), Dimitri A. Sverjensky (V), Adegbola Tokun (H), Daniel G. Weight (O), Philip Zion (O).

Student Status

Dorothy F. Atwood (H), Nikolaus Christou (G), Paul E. Filmer (GP), Sheryl Franklin (H), Ronald A. Harris (T), Daene G. McKinney (H), Charles D. Stone, Brian Woodruff (A).

Meetings

Geophysical Year

New Listings

A boldface meeting title indicates sponsorship or cosponsorship by AGU.

May 14–16, 1984 Geological Assoc. of Canada and Mineralogical Assoc. of Canada Joint Annual Meeting, London, Ontario. (N. D. MacRae, Dept. of Geology, Univ. of Western Ontario, London, Ontario, N6A 5B7, Canada.

Change

June 26–28, 1984 Symposium of the Achievements of the International Magnetospheric Study, Graz, Austria. Sponsor, Scientific Committee on Solar-Terrestrial Physics of ICSU. (J. G. Roederer, Geophysical Institute, Univ. of Alaska, Fairbanks, AK 99701.) New date is shown.

The complete Geophysical Year last appeared in the August 30, 1983, *Eos*.

GAP

Separates

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Aeronomy

0410 Absorption and scattering of radiation (particles or waves)
IONOSPHERIC CAVITONS AND RELATED NONLINEAR EFFECTS
A. Y. Wong (Department of Physics, University of California, Los Angeles, CA 90024) J. Santoru, C. Darrow, L. Wang and J. G. Roederer
Results from ionospheric modification experiments, laboratory simulation experiments, and theoretical studies support a physical model of ionospheric cavitons. Cavitons, or density cavities, may occur naturally and may be enhanced during modification experiments using high power electromagnetic waves. Their presence alters the excited electrostatic wave characteristics and the reflection properties of the EM waves. The relationship of cavitons to other nonlinear phenomena and their role in ionospheric modification experiments are discussed. The recently completed HIPAS HF Transmitting Facility is also described. (Cavitons, HIPAS facility, ionospheric modification).
Rad. Sci., Paper 3S1010

0430 Composition (atomic or molecular)
NITRIC OXIDE IN THE UPPER STRATOSPHERE: MEASUREMENTS AND GEOPHYSICAL INTERPRETATION
J. J. Horvath (Space Physics Research Laboratory, University of Michigan, Ann Arbor, Michigan, 48109), J. E. Frederick, N. Orsini, A. R. Douglass
A rocket-borne parachute-deployed chemiluminescence instrument has obtained seven new measurements of atmospheric nitric oxide for altitudes between 30 and 50 km at mid-latitudes. These results, when combined with profiles measured by an earlier version of the instrument, cover all four seasons and provide a more comprehensive picture of upper stratospheric nitric oxide than has been available previously. At the highest altitudes studied, the vertical gradient in mixing ratio displays positive and negative values during different observations with the largest values tending to appear at the greatest heights in summer. Examination of the differences among the profiles, which exceed a factor of 3 near the stratopause, suggests that they arise from the action of transport processes which carry air into the mid-latitude upper stratosphere from regions of the atmosphere that contain widely different odd nitrogen abundances. (Nitric oxide, chemiluminescence).
J. Geophys. Res., Green, Paper 3C1453

Electromagnetics

0701 Antennas
IMPEDANCE MEASUREMENTS ON A VLF MULTI-TURN LOOP ANTENNA IN A SPACE PLASMA SIMULATION CHAMBER
H. C. Koons (The Aerospace Corporation, P. O. Box 92957, Los Angeles, California, 90009) M. H. Dazey and B. C. Edgar
The Space Sciences Laboratory of The Aerospace Corporation is presently defining an experiment to test a loop antenna configuration for a VLF transmitter in the ionosphere. The primary objectives of the experiment are to validate existing models for radiation by a loop antenna and to study the performance of the antenna in the ionospheric plasma. A one-third scale model of the antenna has been constructed. Impedance measurements have been made on the model in a 5-m diameter space plasma simulation chamber at NASA Lewis Research Center. The measurements confirm that the reactance of the antenna in an ionospheric plasma is essentially identical to its free space self inductance. The effective series resistance of the circuit increases with frequency. The losses are attributed to power transferred to plasma turbulence. (Loop antenna, plasma, vlf).
Rad. Sci., Paper 3S1444

0780 Electromagnetics (Scattering)
[illegible]
Oleg I. Yordanov (Institute of Electronics, Sofia, Bulgaria)
The scattering of high frequency scalar waves by a reflecting surface containing two-scale, two-dimensional random irregularities is considered. All possible specular contributions, as well as the effects of large-scale shadowing, are accounted for. Expressions for the average field and the average intensity are derived and evaluated numerically. The results obtained differ qualitatively from those known in the literature and agree with the latest experimental data. (Scattering, rough surfaces, shadowing).
Rad. Sci., Paper 3S1417

0799 General (Surface Waves)
THE MODAL SPECTRUM OF A GROUNDED GYROMAGNETIC SLAB ALSO A PERPENDICULAR OR PARALLEL AXIS OF MAGNETIZATION
N. K. Uzunoglu (Dept. of Electrical Eng., National Tech. University of Athens, 147, Greece), J.L. Tsalamengas and J.G. Fikioris
Electromagnetic wave propagation along a lossless, grounded, gyromagnetic slab, magnetized perpendicular or parallel to the ferrite-air interface, is considered analytically for an arbitrary direction of propagation parallel to the slab surface. In addition to the usual surface waves, the present structure is found to support proper complex ones, which, corresponding to evanescent modes, carry no real power, but may store reactive energy. Propagation conditions are discussed and, also, dispersion relations and field intensity distributions for the supported modes are derived. A variety of related numerical results is presented in several plots.
Rad. Sci., Paper 3S1517

Exploration Geophysics

0920 Magnetic and electrical methods
DISCOVERY OF A MINERALIZED BRECCIA AREA USING GRADIENT ARRAY INDUCED POLARIZATION
S. H. Ward (Mining Geophysical Surveys, Inc., 2100 E. Grant Road, Tucson, AZ 85719) [illegible] and [illegible]
The Promontorio breccia pipe located in southern Sonora, Mexico, has been mined intermittently for silver since the turn of the century. Mineralization occurs as sulfides in the matrix of the breccia. Two to five percent pyrite also occurs in the praminceral andesite that the breccia pipe has intruded.
Geologic mapping led to the discovery of a small, mineralized breccia in andesite 800 m west of Promontorio. The discovery of this breccia encouraged the search for other hidden mineralized breccias in areas obscured by postmineral alluvium. Exploration of the covered areas was carried out with an induced polarization (IP) and resistivity survey after a test line indicated that a distinct IP anomaly occurs over the Promontorio breccia pipe. The gradient array was chosen as the most effective electrode configuration to explore the covered areas because it can provide rapid detailed IP coverage necessary to locate small breccia pipes.
Several anomalous IP zones were located. The most interesting one has an apparent response of 60 to 90 msec in low-resistivity rocks similar to Promontorio. Additional information provided by dipole-dipole profiles indicates that this anomalous zone is close to the surface and about 20 m wide with a vertical to steep dip. Trenching and drilling confirmed the presence of a 20-m wide alongate breccia with sulfide mineralization similar to Promontorio. Silver grades were marginal for making ore in 1977.
GEOPHYSICS, VOL. 48, NO. 10

0930 Seismic methods
RECOVERY OF THE ACOUSTIC IMPEDANCE FROM REFLECTION SEISMOGRAMS
D. W. Oldenburg (Department of Geophysics and Astronomy, University of British Columbia, Vancouver, B.C., Canada V6T 1W5) T. Scheuer, and S. Levy
The paper examines the problem of recovering the acoustic impedance from a band-limited normal incidence reflection seismogram. The convolutional model for the seismogram is adopted at the outset, and it is therefore required that initial processing has removed multiples and recovered true amplitudes as well as possible. In the first portion of the paper, we investigate the effect of inhibiting the deconvolved seismic trace (that is, the band-limited version of the reflectivity function) into the standard recursion formula for the acoustic impedance. The formalism of linear inverse theory is used to show that the logarithm of the normalized acoustic impedance estimated from the deconvolved seismogram is approximately an average of the true logarithm of the impedance. Moreover, the averaging function is identical to that used in deconvolving the initial seismogram. The advantage of these averages is that they are unique; their disadvantage is that low-frequency information, which is crucial to making a geologic interpretation, is missing.
We next present two methods by which the missing low-frequency information can be recovered. The first method is a linear programming (LP) construction algorithm which attempts to find a reflectivity function made of isolated delta functions. This method is computationally efficient and robust in the presence of noise. Importantly, it also lends itself to the incorporation of impedance constraints if such geologic information is available. A second construction method makes use of the fact that the Fourier transform of a reflectivity function for a layered earth can be modeled as an autoregressive (AR) process. The missing high and low frequencies can thus be predicted from the band-limited reflectivity function by standard techniques. Stability in the presence of additive noise on the seismogram is achieved by predicting frequencies outside the known frequency band with operators of different orders and extracting a common signal from the results.
Our construction algorithms are shown to operate successfully on a variety of synthetic examples. Two sections of field data are inverted, and in both the results from the LP and AR methods are similar and compare favorably to acoustic impedance features observed at nearby wells.
GEOPHYSICS, VOL. 48, NO. 10

Hydrology

3110 Erosion and Sedimentation
ORGANIC DETRITUS PARTICLES: INITIATION OF MOTION CRITERIA ON SAND AND GRAVEL BEDS
J. S. Fisher (Civil Engineering Department, North Carolina State University, Raleigh, North Carolina, 27650)
Laboratory experiments were used to extend the application of the Shields entrainment function to both organic sediments and inorganic sediments overpassing a bed composed of particles of a different size. A total of 89 flume experiments were conducted to simulate organic sediment motion over sand and gravel stream beds. Although the study emphasis was on organic particles, some of the tests included inorganic sediments. The bed particle diameters ranged from 0.7×10^{-3}m to 22×10^{-3}m while the organic particle diameters ranged from 0.56×10^{-3}m to 7.15×10^{-3}m. A visual technique was used to determine the initiation of motion. The laboratory results were used to derive a modified Shields relationship which includes both the transported and bed particle characteristics. This modified Shields function predicts the initiation of motion of both organic and inorganic particles overpassing beds whose composition is significantly different than these particles. These results have direct application to the prediction of incipient motion of organic and inorganic detritus particles in streams and estuaries. (Detritus, estuarine sedimentation)
Water Resour. Res., Paper 3W1197

3199 Miscellaneous (Drinking Water Risks)
THE RISKS OF DRINKING WATER
E. A. C. Crouch, R. Wilson and L. Zeise (Energy and Environmental Policy Center, Jefferson Physical Laboratory, Harvard University, Cambridge, Massachusetts, 02138)
Exposure to the low levels of organic compounds found in drinking water might cause a variety of health effects, cancer being one of great concern. The estimation of cancer risk is uncertain, which may in part explain why cancer risk is not properly considered in establishing drinking water standards. Current standards for a given chemical or class of chemicals do not account for the presence of other pollutants; chemicals which have not been tested in long term oral bioassays are generally ignored; and the uncertainties of risk calculations are not explicitly considered. To better quantify risks from drinking water, we apply procedures which incorporate measures of uncertainty into the risk calculation and consider all chemicals included in a water analysis. This procedure is demonstrated by calculating risks for several US water supplies. Our results show that some might pose moderately high risks. (Water standards, cancer risk measurement).
Water Resour. Res., Paper 3W1460

Meteorology

3735 Electrical Phenomena
CHARGE SEPARATION DURING RUPTURE OF SMALL WATER DROPS IN TRANSIENT FLOWS
D. Dreyfuss and F. Tonkin (Department of Mechanical and Aerospace Engineering, Rutgers University, New Brunswick, New Jersey, 08903)
When water drops rupture, there is usually a separation of charge associated with the shearing of a surface electrical double layer. This phenomenon has long been known and studied in large drops in steady flows. We have extended these results to small (1–2 mm) droplets in the transient flow behind a shock wave. Such charge separation could account for the lightning observed over volcanoes and above-ground thermonuclear explosions. A charge regeneration also occurs in common thunderstorms due to thunder-induced drop fragmentation, but this effect gives only a minor contribution to the charge distribution in a thundercloud.
J. Geophys. Res., Green, Paper 3C1231